Cellulose Acetate Treatment for Textile Insulation—Engineering Development

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The development of a cellulose acetate lacquer treatment for textile insulated wire has made available an improved type of wire for telephone central office use. The desired improvement in electrical characteristics is obtained when the textile fibers are laid down and covered by the cellulose acetate film.

The accompanying graphs show the comparative electrical characteristics at various humidities, of wires insulated with commercial and purified cotton and silk servings, before and after treatment with cellulose acetate lacquer.

Introduction

THE improved standards of transmission required for present-day telephone communication have greatly increased the importance of improved electrical characteristics for telephone central office wire insulation. At the same time the tremendous growth of telephone systems, together with the increase in complexity of central office equipment due to the introduction of dial switching apparatus, has increased the quantity of insulated wires required to such an extent that the use of comparatively cheap materials is a matter of large economic importance. Silk and cotton yarns applied in the form of wrappings or braidings have been the standard materials for telephone central office wire insulation for many years. These materials in proper combinations and supplemented in certain cases by enamel and impregnating waxes provide sufficient dielectric strength to withstand the comparatively low voltages employed to operate telephone apparatus. This type of insulation also fulfills certain controlling mechanical requirements, in that it occupies small space, is not easily damaged by normal handling and can be applied in a large number of color combinations. On the other hand, there are disadvantages attendant upon the use of textile insulation, the most serious of which is the wide variation in insulating properties of such materials under different conditions of atmospheric humidity and temperature, caused mainly by changes in the moisture content of the materials.

The efforts which have been made to improve textile insulation in this respect have had a two-fold objective, namely, to provide at moderate cost a super-quality insulation for use where it is important to have the best electrical characteristics obtainable, and to improve

cotton sufficiently to permit its use instead of silk as far as possible for general purposes. The latter has considerable direct economic importance because of the large difference in cost of insulating silk and cotton and the quantities of the materials involved.

Within the past three years, two methods of improving the electrical characteristics of textile insulation have been brought into commercial use. The first is the purification of silk and cotton whereby electrolytic impurities such as sodium and potassium salts inherent in the commercial materials are removed by a simple and inexpensive washing process.[1] The second is the treatment of textile insulated wire with cellulose acetate, which is the subject of discussion in this paper and the contemporary paper "Cellulose Acetate Treatment for Textile Insulation-Development of the Manufacturing Process" by Messrs. C. R. Avery and H. Kress.

Cellulose acetate became of interest in connection with insulation problems several years ago, when it was investigated in the form of artificial silk for use as a substitute for natural silk in wire and cable insulation. At that time, the material was found to possess excellent electrical characteristics and satisfactory stability, but it did not prove to be economically satisfactory as a general substitute for silk because the physical characteristics of the yarn made its use on standard high speed insulating machinery difficult. Application of the material in the form of a lacquer to cotton or silk insulation appeared to offer more promise and has proven advantageous, as will appear from the following discussion. The treatment, as now applied to telephone central office wire insulation, consists in the formation of a coating of the material on the textile insulated conductor, by passing the conductor through an acetone solution of pure cellulose acetate and subsequent evaporation of the solvent. Pure cellulose acetate without the addition of a plasticizer is used, because thus far it has been found more satisfactory than a compounded material as regards the controlling requirements for central office wire insulation, namely good electrical characteristics, slow burning properties and stability. Therefore, this discussion is confined to the characteristics and use of the pure material.

Properties of Cellulose Acetate

In the investigation of a material to be used for insulating purposes, it is necessary to examine the processes by which the material is manu-

[1] "The Predominating Influence of Moisture and Electrolytic Material upon Textiles as Insulators," R. R. Williams and E. J. Murphy, *A. I. E. E. Transactions*, April, 1929. "Purified Textile Insulation for Telephone Central Office Wiring," H. H. Glenn and E. B. Wood, *A. I. E. E. Transactions*, April, 1929.

factured to determine whether there is anything inherent in these processes which would affect the use of the product. This is particularly pertinent in the case of an insulating material which is to be used for a period of twenty years or more, as in a telephone exchange.

The manufacture of cellulose acetate is described hriefly by the following operations:

In the first or acetylation process, cellulose fibers, usually cotton, are treated with glacial acetic acid and acetic anhydride, together with a catalyst such as sulphuric acid, until the fibers are completely acetylated and pass into solution. The acetate obtained at this stage is brittle, of low tensile strength and insoluble in the commercial solvents. Therefore, the solution is subjected to a hydrolizing process in which water is added and the mixture allowed to stand until hydrolysis has been carried to the point at which the cellulose acetate becomes acetone soluble. The acetyl content is somewhat reduced in this step and serves as an index to the extent of hydrolysis. The solution is then poured into water and the cellulose acetate precipitated, after which it is given a purification treatment until the mass is free from acid and then dried in warm air.

The completed product is a porous, flaky mass, white in color, which, when dissolved in acetone, gives a solution nearly colorless but with a slight amber tinge.

From the above outline of the processes of manufacture, the importance of the acetyl content of the product is obvious. If the acetyl content is too high, the material is not soluble in acetone and if the acetyl content is too low, the hydrolysis has been carried too far and the acetate becomes partly soluble in water. Such an acetate would be unsatisfactory for insulation on account of inferior electrical characteristics under humid atmospheric conditions.

By changes in control of the acetylation and hydrolizing processes various kinds of cellulose acetate may be obtained which, with the same general composition and acetyl content, give different viscosities of solution when dissolved in a solvent. For example, films for experimental purposes have been made from cellulose acetates which vary in viscosity as much as a hundred fold with the same proportions of cellulose acetate and solvent. For lacquer and films, a low viscosity acetate is employed, while for plastics, cellulose acetates of high viscosity are usually specified.

For use as insulation, it is necessary that the acetate be stable throughout the life of a telephone exchange. In other words, it must retain its good electrical characteristics and transparency for a period of twenty years or more though exposed, as it will be, to variations of

temperature, indoor sunlight exposure and atmospheric moisture. From the standpoint of stability, especially as regards a possible increased rate of deterioration with time, it is important that the material shall be essentially free from impurities which might be introduced in the acetate manufacturing process.

Cellulose acetate film has very desirable electrical properties characterized by high dielectric strength, low conductivity and low a-c. capacitance and conductance. It absorbs much less moisture than silk, cotton or wool. It has a specific gravity of about 1.25 and a dielectric constant of from 5.5 to 6.0 at 1,000 cps. under atmospheric conditions of 70° F. and 50 per cent relative humidity.

The acetate film is strong and tough and not easily injured by handling. The transparency of the film is such that the colored threads used in the color scheme for identification purposes in telephone wires and cables can be readily seen through the acetate coating.

Cellulose acetate film is very stable under normal conditions and when exposed to artificial aging tests. Tests made in the Laboratories with acetate film exposed to high humidities and high temperatures for several years indicated that there was very little deterioration of the film in its electrical or other physical properties. The electric characteristics of the film were not appreciably affected by this exposure and no discoloration of the film was apparent.

As compared to cellulose nitrate, cellulose acetate is a much more desirable material on account of its slow-burning characteristics, and the fact that the gases given off on the combustion of the acetate are comparatively non-toxic. From these standpoints the hazards involved in the use of the nitrate preclude its use in the telephone central office. Acetate film does not turn yellow with age to the same extent as the nitrate film.

Pure cellulose acetate film is somewhat hard and brittle. This is, of course, a disadvantage because it tends to make the treated wire less flexible than wire with untreated insulation which introduces new problems in the handling of the treated wire. A large amount of work has been done with a view to obtaining a plasticizer for cellulose acetate which will add the property of flexibility to the film without affecting the desirable characteristics which the pure acetate film now possesses. The problem of obtaining such a plasticizer is difficult inasmuch as the general tendency of such materials is to impair the electrical characteristics, lower the tensile strength, and increase the inflammability of the film when used in amounts sufficient to produce a film of desired flexibility.

Treatment of Textile Insulated Wire

The cellulose acetate treatment of wire consists essentially in passing the textile insulated conductor through a thin solution of cellulose acetate dissolved in acetone, then through a wiping die to remove the excess lacquer and finally into a heated drying chamber where the solvent is evaporated. This process is repeated several times, usually six, to build up a film of satisfactory thickness and smoothness. The application of heat in the drying process is necessary for two reasons. First, the evaporation of the solvent tends to lower the temperature of the wire considerably and if the temperature falls below the dew point of the surrounding air, moisture will condense on the wet lacquer film, causing it to turn white and opaque. In the second place, the evaporation of the solvent must be rapid in order that the speed of the wire through the lacquering machine may be such as to make application of the treatment to large quantities of wire commercially practicable.

In the earlier stages of the investigation, the insulated wire was thoroughly dried before being treated to eliminate the moisture in the textile. In addition, the wire was treated under vacuum with the object of thoroughly impregnating the whole textile covering and preventing entrance of moisture into the textile after the impregnating process was completed. However, it was found that even with vacuum impregnation, the cellulose acetate did not penetrate the insulation to an appreciable depth, although the solvent appeared to penetrate to the conductor and thoroughly wet the insulating materials. Also, it was found that the coating of cellulose acetate did not prevent the entrance of moisture into the textile to any appreciable extent.

In consideration of these facts, it was concluded and confirmed by tests that the improvement in electrical characteristics of cellulose acetate treated wire under conditions of high humidity is due mainly to the barrier of high resistance lacquer film interposed in the leakage paths formed by moisture in the textile insulation. It may be seen from Fig. 1 that the fibers of untreated cotton insulation project in all directions, and in a twisted pair, interweave to increase the effective area of contact between the conductors and provide a medium for direct leakage paths when moisture is present. With the fibers smoothed down and covered by the application of several layers of lacquer film, the effective area of contact is decreased and any leakage which takes place must be either through or across this relatively high resistance film. In confirmation of this conclusion, it has been found by repeated tests, that a very reliable indication of the improvement in electrical characteristics which may be expected in a treated wire is

obtained by observing the extent to which the textile fibers have been laid and covered by the lacquer film. If the surface of the wire is smooth and practically free from projecting fibers as is shown in the photograph, the wire may be expected to exhibit normal improvement.

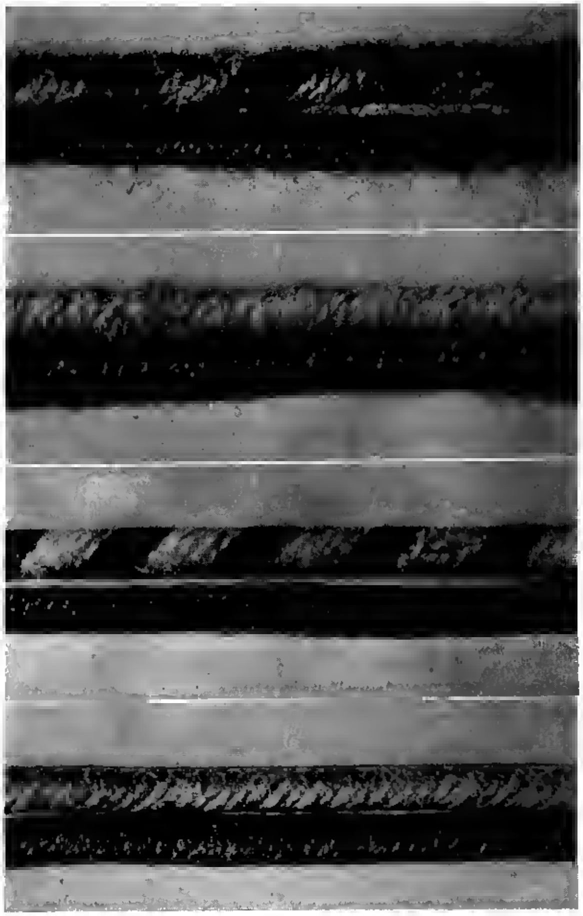

Fig. 1—Textile insulated 22-gauge wires before and after treatment with cellulose acetate. The cellulose acetate covering prevents direct contact between textile fibres of adjacent wires and reduces current leakage.

For example, when textile insulated conductors are twisted and then treated with cellulose acetate, practically no improvement in electrical characteristics of the pair is obtained, because the interlocking fibers of the two conductors which provide the direct leakage paths are not separated. A similar effect has been observed in the treatment of coils

wound with textile insulated wire. If the treatment is applied to the wire before winding, the desired improvement in stability of the constants is obtained. Coils treated after winding, however, show very little improvement since the lacquer does not penetrate but merely provides a superficial covering of film which does not exclude moisture or break up the interlocking fibers between turns.

It has been found that increasing the thickness of the lacquer film, beyond that required to cover the fibers and provide a smooth surface, results in relatively small additional improvement in the insulation. This is of economic importance since, with proper methods of application, a relatively thin film may be practically as effective as a thick one requiring a considerably greater quantity of material, and a rapid check on the quality of the product can be made by visual inspection of the surface condition of the treated insulation.

Electrical Characteristics of Treated Wire

The accompanying graphs show a comparison of the electrical characteristics of untreated and treated cotton and silk insulation, respectively, for a cycle of relative humidity ranging from 65 per cent to 90 per cent and back to 65 per cent at a constant temperature of 85° F. The comparison is given for both commercial and purified materials as a matter of general interest, although purified textiles are now used exclusively in Bell System central office wire insulation. The graphs are plotted from data on samples of wire insulated with silk and cotton taken at random from stocks of commercial and purified materials and treated with cellulose acetate under conditions of regular production. The values given by the graphs should not be considered as applying quantitatively to any standard type of central office wire but are intended to show, on a comparative basis, the extent to which the commercial and purified materials have been improved by treatment with cellulose acetate, and the rather remarkable improvement in the characteristics of commercial textiles by both purification and cellulose acetate treatment.

Perhaps the comparison of greatest general interest is that of insulation resistance, Figs. 2 and 3, since it is important in any electric circuit that the insulation shall be capable of preventing undue energy loss from direct current leakage. From these graphs, it is seen that the insulation resistance of commercial cotton may be improved from 100 to 300 fold by treatment with cellulose acetate and in the order of 500 to 2,000 fold by purification plus acetate treatment depending upon the relative humidity. Thus, as indicated by insulation resistance, acetate treated purified cotton becomes a comparatively high

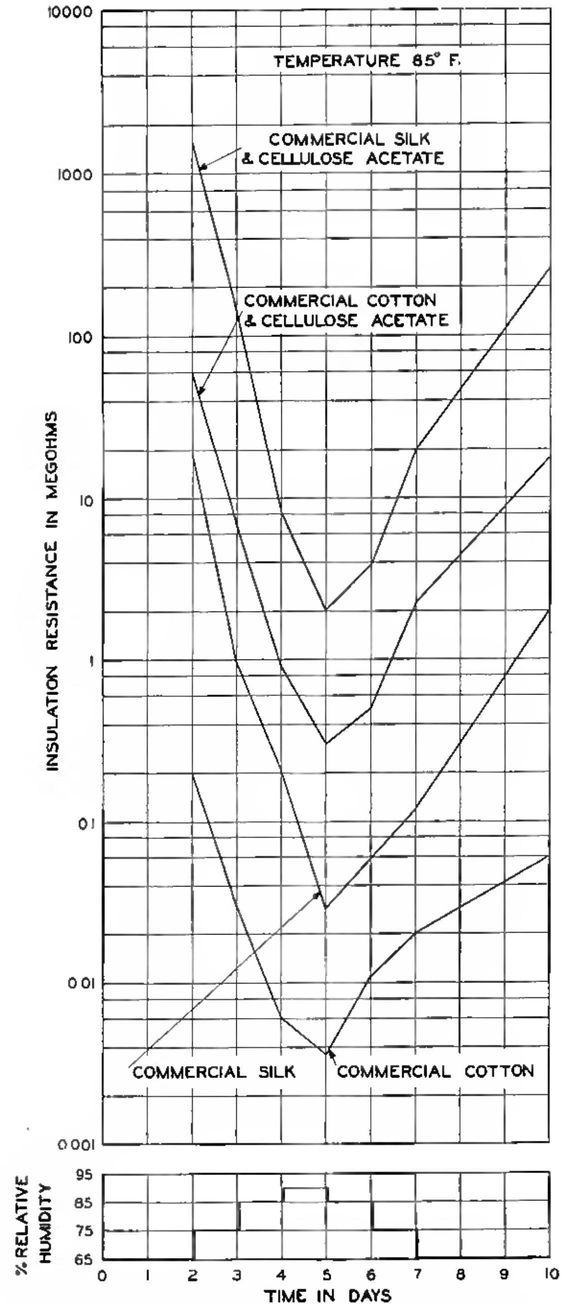

Fig. 2—D-C. insulation resistance of 50 feet of twisted pair 22-gauge wire insulated with double servings of equal thickness.

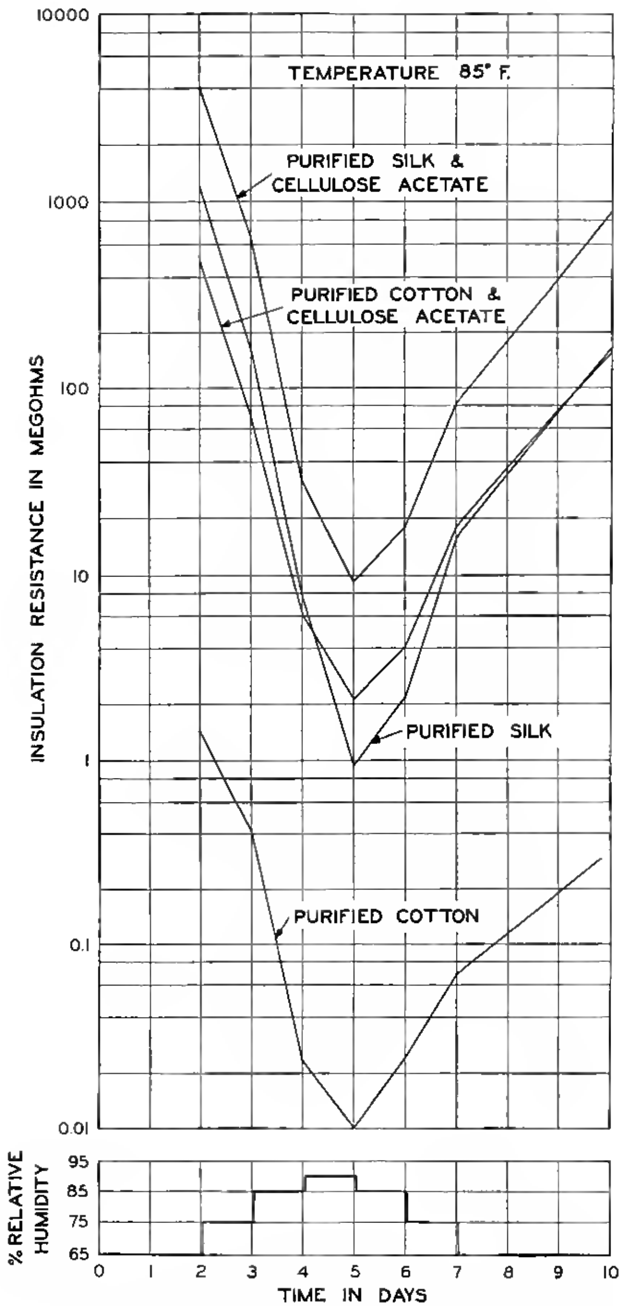

Fig. 3—D-C. insulation resistance of 50 feet of twisted pair 22-gauge wire insulated with double servings of equal thickness.

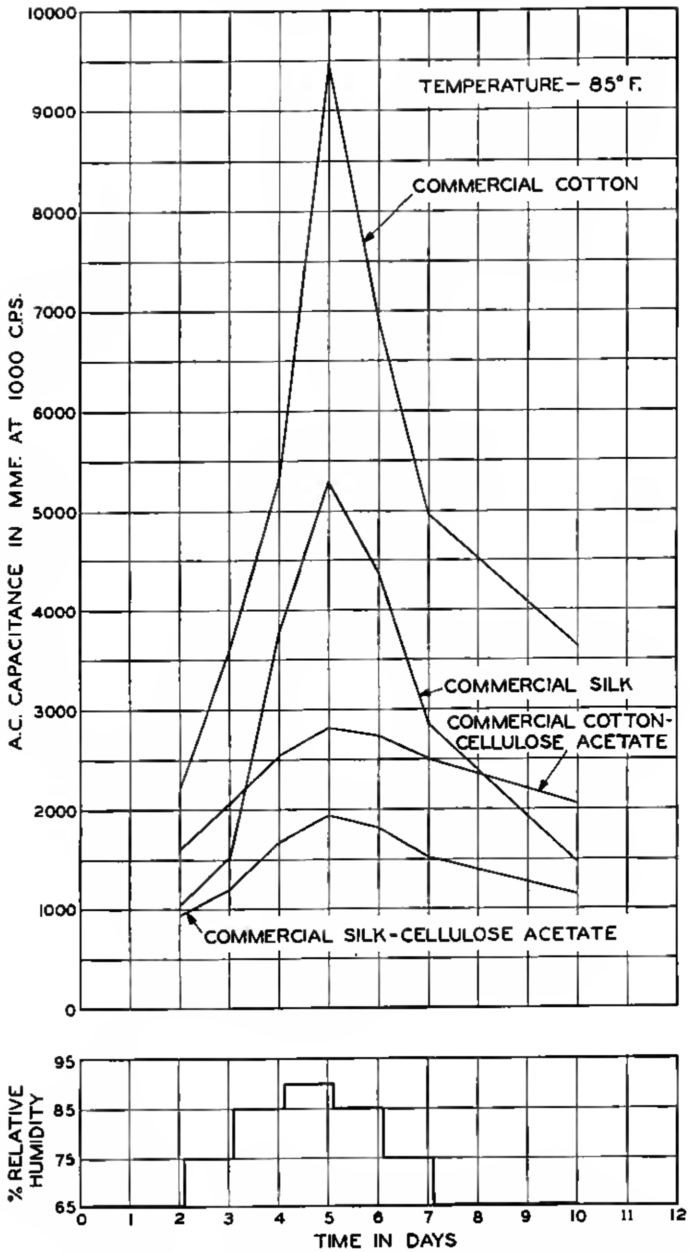

Fig. 4—A-C. capacitance of 50 feet of twisted pair 22-gauge wire insulated with double servings of equal thickness.

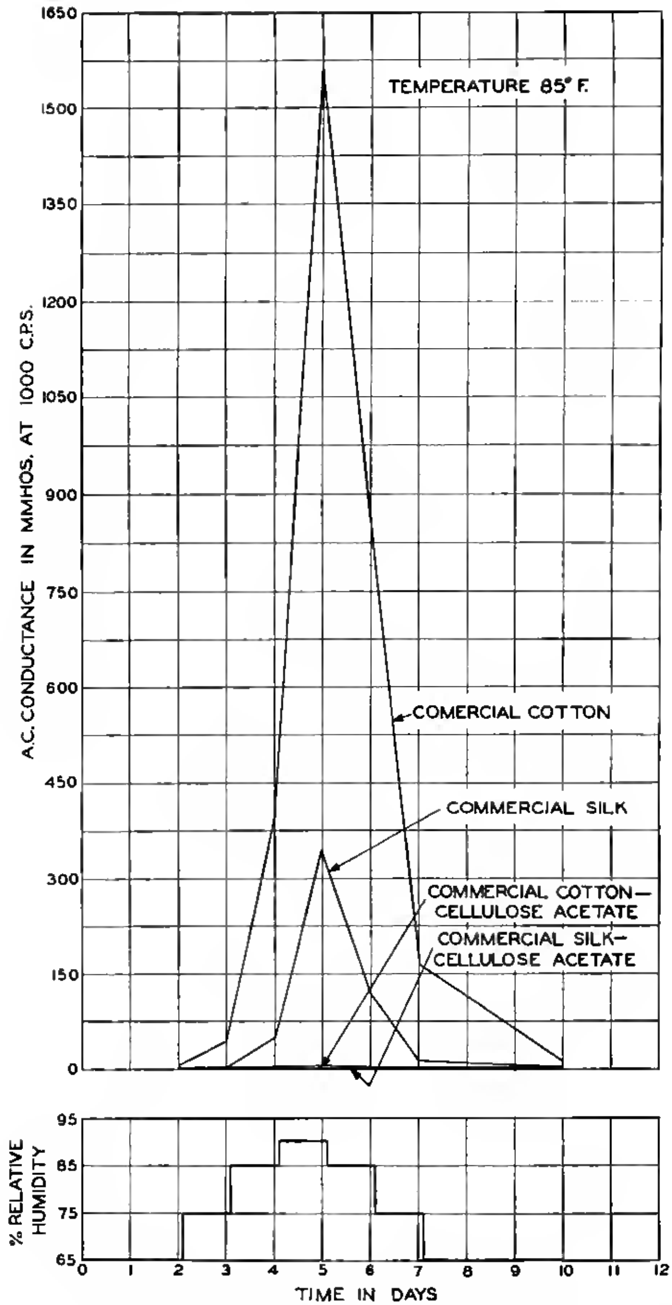

Fig. 5—A-C. conductance of 50 feet of twisted pair 22-gauge wire insulated with double servings of equal thickness.

grade insulation suitable for many purposes where more expensive combinations of silk and cotton have been required heretofore.

From the telephone transmission standpoint, the a-c. characteristics of capacitance and conductance are of particular importance because they determine the loss in transmission of energy at voice and carrier frequencies, which must be kept at a minimum to maintain high quality of telephone communication. A comparison of a-c. capacitance and conductance at a frequency of 1,000 cycles for commercial and purified

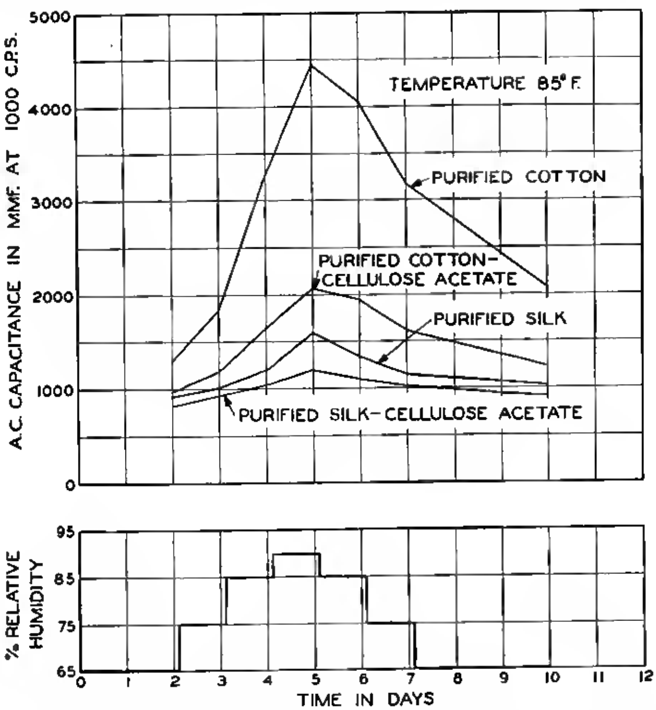

Fig. 6—A-C. capacitance of 50 feet of twisted pair 22-gauge wire insulated with double servings of equal thickness.

silk and cotton with and without cellulose acetate treatment is shown in Figs. 4, 5, 6 and 7. The data represented by these graphs converted into transmission loss units are shown in Figs. 8 and 9. These data derive their main significance from the large reduction in capacitance and conductance at the higher humidities, and the fact that it is the variation of these transmission loss characteristics which is of the greatest importance from the telephone transmission standpoint. Losses, if fixed in value, can be compensated for, but if they are subject to wide variations such as those illustrated by the samples of

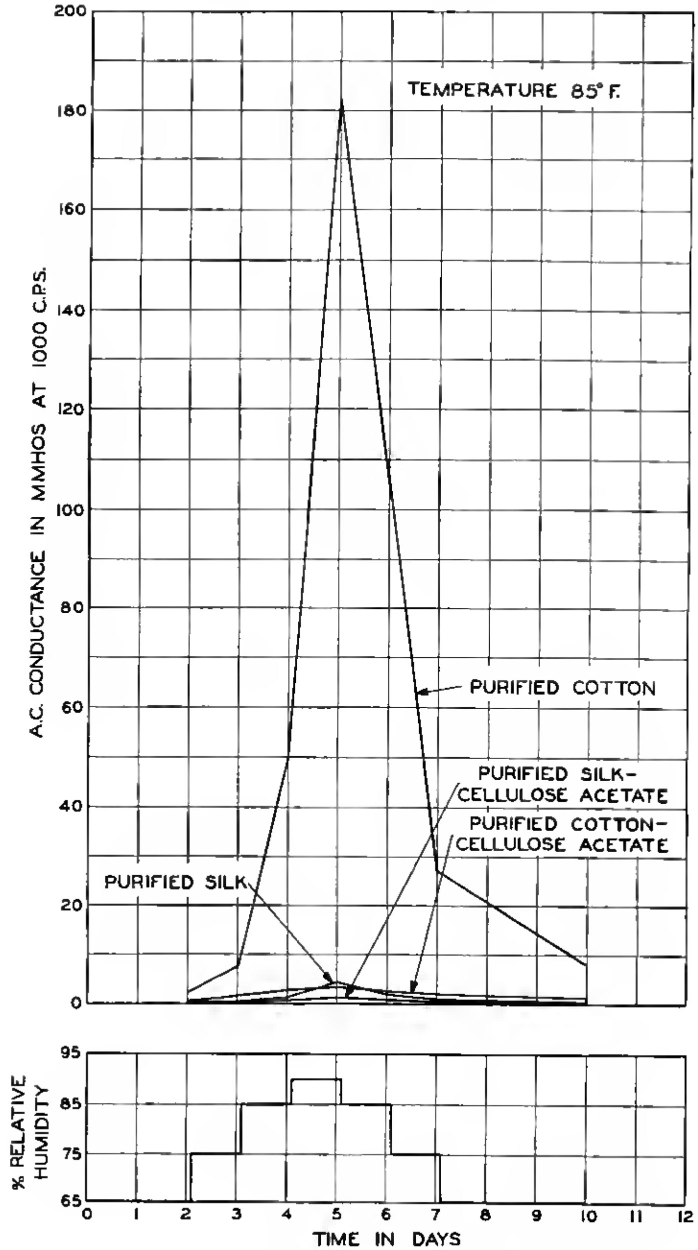

Fig. 7—A-C. conductance of 50 feet of twisted pair 22-gauge wire insulated with double servings of equal thickness.

untreated commercial textiles, the matter of compensation becomes difficult or entirely impracticable.

In addition to maintaining transmission losses at a minimum, it is required in certain toll apparatus that the capacitance and conductance

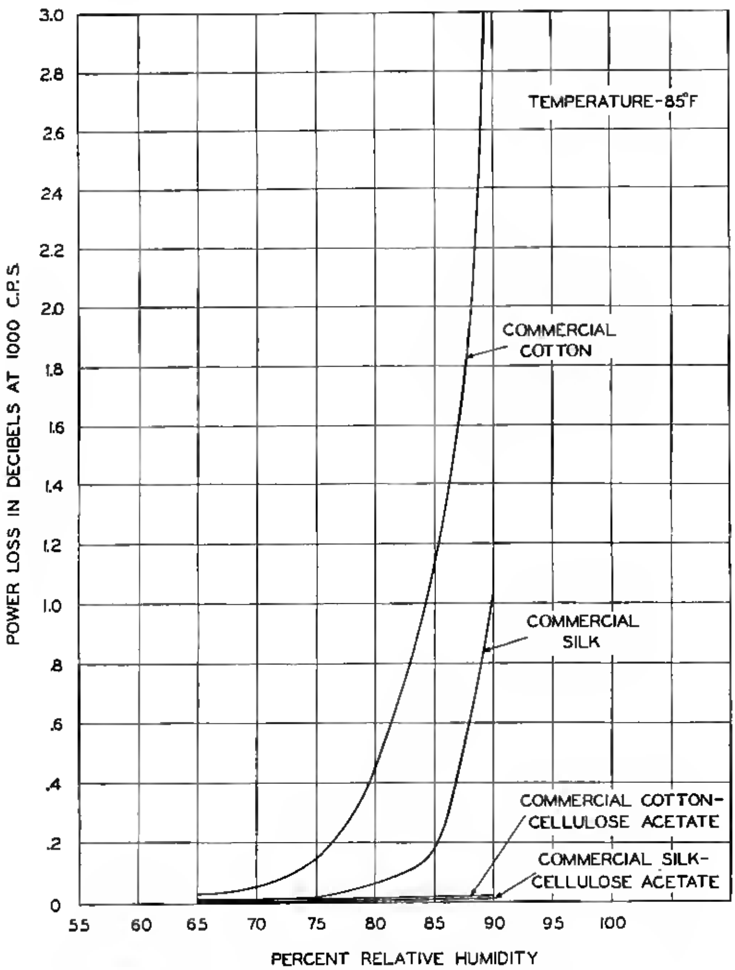

Fig. 8—Transmission loss in 50 feet of twisted pair 22-gauge wire insulated with double servings of equal thickness.

of the parts of the electric circuits be balanced to prevent interference between adjacent circuits which would increase the noise level and impair the quality of voice transmission. Such circuits are usually wired with four-conductor wire and it is required that the characteristics of the insulation and the spacing of the conductors shall be suffi-

ciently uniform to preserve an electrically balanced circuit. From Figs. 4, 5, 6 and 7, it is seen that the capacitance and conductance of commercial silk and cotton insulation are greatly reduced by cellulose acetate treatment and that the purified materials are also improved

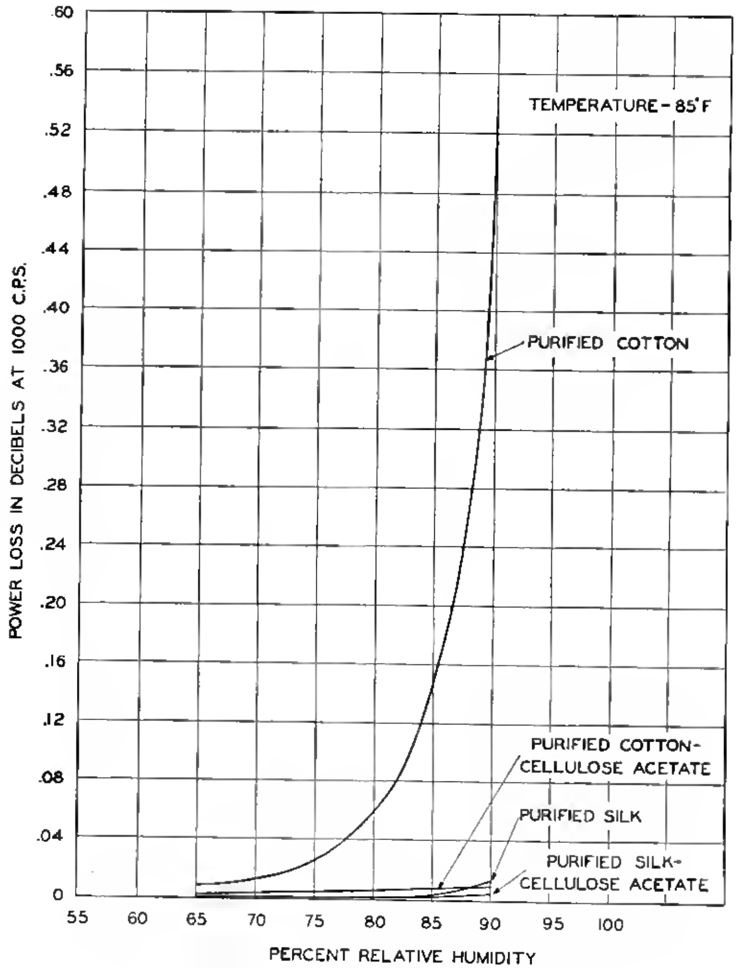

Fig. 9—Transmission loss in 50 feet of twisted pair 22-gauge wire insulated with double servings of equal thickness.

considerably in that respect. It is evident, therefore, that the addition of cellulose acetate treatment to purified textile insulation will result in greater uniformity in the electrical characteristics of the product than is possible by use of purified insulation alone, since the effects of any lack of uniformity in the purified material, due to variable results

in the purifying process, will be practically nullified by the acetate treatment.

An interesting example of how cellulose acetate treatment improves the electrical balance of a circuit is given in Fig. 10, which shows the capacitance unbalances between phantom and side circuits in a four-conductor wire for toll use. The capacitance unbalance is the main cause of electrical interference between the two circuits mentioned above and it is desirable to have this value as low as possible. Although there are some differences in design in these two types of wire, practically all the improvement is due to the acetate insulation.

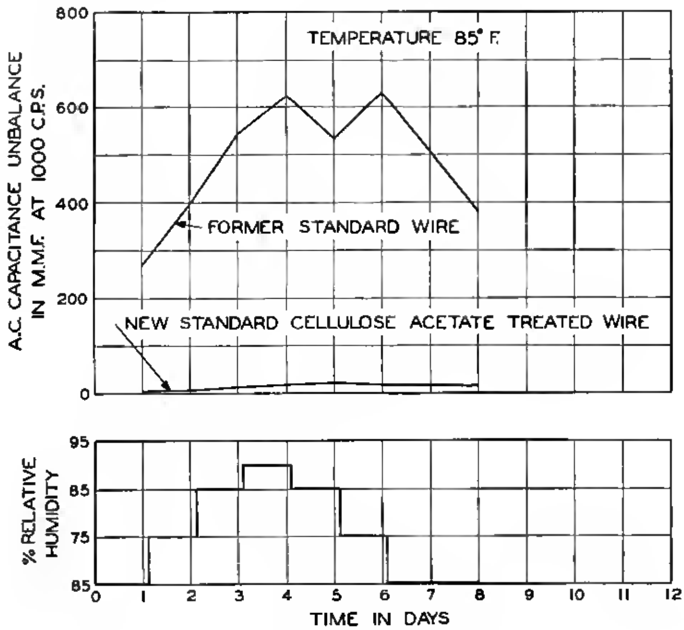

Fig. 10—A-C. capacitance unbalance between the phantom and side circuits of 50 feet of quadded 22-gauge wire.

Application to Apparatus

Advantages in the use of cellulose acetate treated insulation are derived from several sources of which the most important is the improvement in electrical characteristics of cotton and silk, as illustrated by the foregoing graphs. For example, this improvement is sufficient in many cases to permit the substitution of cotton for silk, with a resulting substantial reduction in cost. In other cases, silk has been retained and a cable of much higher quality has been made available

for use in toll equipment where the best electrical characteristics obtainable are needed.

The improved electrical characteristics of cellulose acetate treated insulation also make possible the elimination of enamel in a large amount of wire and cable where it has formerly been required to prevent excessive current leakage under conditions of high humidity. This is of economic importance because of the difficulty of removing the enamel preparatory to soldering the wire to terminals, and the precautions necessary to prevent trouble from faulty soldered connections, which increase considerably the cost of installation and maintenance of apparatus.

In distributing frame wire the use of cellulose acetate treated insulation has been found to be particularly advantageous. This type of wiring cannot be installed permanently in cabled form, as is the practice with practically all other types, because of controlling equipment and service conditions, and in order to guard against fire hazard from a large mass of loose wiring, the insulated conductor has, heretofore, been covered with a cotton braid impregnated with flameproofing salts. These salts, because of their hygroscopic and electrolytic nature, have a deleterious effect on the electrical characteristics of the insulation under humid conditions and introduce the danger of excessive leakage and corrosion, particularly near terminals. Exhaustive tests have proved that cellulose acetate treated insulation, without the addition of flameproofing salts, will be as satisfactory as the old type with respect to safety, and the elimination of salts has made it possible to design a wire which is greatly superior to the old type electrically, considerably less expensive to manufacture and smaller in size.

Another advantage in cellulose acetate treatment is its effect in preventing unwrapping and fraying of the textile at terminals. With the old standard wires, fraying is prevented by impregnating the insulation near the ends with wax. This wax treatment is undesirable in that it adds to the flammability of the insulation, tends to obscure the marking colors and collects dust. Cellulose acetate treatment binds the insulation against fraying and provides a smooth glossy surface which does not collect dust readily.

These examples serve to illustrate the more important factors in favor of cellulose acetate treated wire with regard to its application in telephone apparatus. On the other hand, this type of wire has a tendency to be somewhat stiff and springy with the result that its behavior in the operations of twisting, stranding and forming into cables differs considerably from that of the old untreated types. This has made necessary the development of modified manufacturing and

installation methods in connection with these operations and, in certain cases, the observance of special precautions. For examples, in the operation of twisting to form pairs, triples and quads, it is necessary to avoid appreciable stretching of the conductors, as this would crack and loosen the acetate film and impair the appearance of the wire. Fortunately, cracking of the film does not affect the electrical characteristics appreciably, so long as it is not severe enough to permit interlinkage of textile fibers, as discussed in a previous paragraph.

The first application of cellulose acetate treated wire on a regular production basis was made early in 1930, although considerable quantities were installed for service trials in commercial apparatus in 1927. In order to take advantage of the improved electrical characteristics where they are of greatest value, cables and wire used in the toll plant are being changed to employ the new insulation first. Supplementing this program, consideration is being given to extending the use of acetate treated insulation to include wire aggregating annual requirements of the order of three billion feet for the local plant. Application of the new type wire is being made gradually in order that manufacturing and installation methods and technique may be further developed as required in connection with this program.